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A Guide for Estimating Longshore Transport Rate Using Four SPM Methods

by

Philip Vitale

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This report is a guide for computing longshore transport rate. Step-by-step procedures are presented as a guide through an analysis of the available data to the appropriate choice of one or more of the four SPM methods of estimating the longshore transport rate. Each of the four methods is explained with appropriate references or examples.

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PREFACE

This report is a guide to selecting from among the four methods of estimating longshore transport rate given in the Shore Protection Manual (SPM). The information is taken from Chapter 4 of the SPM and presented in a more compact form. The report was prepared under the nearshore sediment transport research program of the U.S. Army Coastal Engineering Research Center (CERC).

The report was written by Philip Vitale, Hydraulic Engineer, under the general supervision of C. Mason, formerly Chief, Coastal Processes Branch (now Coastal Processes and Structures Branch).

Comments on this publication are invited.

Approved for publication in accordance with Public Law 166, 79th Congress, approved 31 July 1945, as supplemented by Public Law 172, 885h Congress, approved 7 November 1963.

Ted E. Bishop

TED E. BISHOP
Colonel, Corps of Engineers
Commander and Director

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CONVERSION FACTORS, U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U.S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	by	To obtain
inches	25.4	millimeters
	2.54	centimeters
square inches	6.452	square centimeters
cubic inches	16.39	cubic centimeters
feet	30.48	centimeters
	0.3048	meters
square feet	0.0929	square meters
cubic feet	0.0283	cubic meters
yards	0.9144	meters
square yards	0.836	square meters
cubic yards	0.7646	cubic meters
miles	1.6093	kilometers
square miles	259.0	hectares
knots	1.852	kilometers per hour
acres	0.4047	hectares
foot-pounds	1.3558	newton meters
millibars	1.0197×10^{-3}	kilograms per square centimeter
ounces	28.35	grams
pounds	453.6	grams
	0.4536	kilograms
ton, long	1.0160	metric tons
ton, short	0.9072	metric tons
degrees (angle)	0.01745	radians
Fahrenheit degrees	5/9	Celsius degrees or Kelvins[1]

[1]To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use formula: C = (5/9) (F -32).

To obtain Kelvin (K) readings, use formula: K = (5/9) (F -32) + 273.15.

SYMBOLS AND DEFINITIONS

a'	volume concentration equal to the ratio of the volume of solids to total volume in a sand deposit
C_g	wave group velocity
C_{gb}	breaker wave group velocity
g	acceleration of gravity
H	wave height
H_b	breaker wave height
$\overline{H}_b$	average breaker wave height
H_s	significant wave height
H_{sb}	significant breaker wave height
H_{so}	deepwater significant wave height
I_ℓ	immersed weight rate of longshore transport
K	empirical coefficient relating I_ℓ to P_ℓ
P_ℓ	longshore component of wave energy flux
$P_{\ell s}$	surf zone approximation of P_ℓ
Q	longshore transport rate
Q_g	gross longshore transport rate
$Q_{\ell t}$	longshore transport rate to the left of an observer onshore looking seaward
Q_n	net longshore transport rate
Q_{rt}	longshore transport rate to the right of an observer onshore looking seaward
T	wave period
α	angle between wave crest and shoreline
α_b	angle between breaking wave crest and shoreline
α_o	angle between deepwater wave crest and shoreline
ρ	mass density of water
ρ_s	mass density of sediment

A GUIDE FOR ESTIMATING LONGSHORE TRANSPORT RATE USING FOUR SPM METHODS

by
Philip Vitale

I. INTRODUCTION

This report presents guidelines for calculating estimates of longshore transport rates which are important in most coastal engineering projects. The step-by-step procedures described herein are condensed from Sections 4.53 and 4.831 of the Shore Protection Manual (SPM) (U.S. Army, Corps of Engineers, Coastal Engineering Research Center, 1977).

II. DEFINITION OF TERMS

The longshore transport rate, Q, is the volumetric rate of movement of sand parallel to the shoreline. Under most conditions, longshore transport takes place in or near the surf zone and is caused by the approach of waves at an angle to the shoreline. Q is expressed in terms of sand volume per unit time (such as cubic yards per year or cubic meters per year). Longshore transport per unit time to the right of an observer onshore looking seaward is Q_{rt}. Transport to the observer's left is $Q_{\ell t}$. The gross longshore transport rate is

$$Q_g = Q_{rt} + Q_{\ell t} \qquad (1)$$

The net longshore transport rate is

$$Q_n = Q_{rt} - Q_{\ell t} \qquad (2)$$

Note that a negative Q_n means net transport to the left.

The quantities Q_{rt}, $Q_{\ell t}$, Q_n, and Q_g have engineering uses. For example, Q_g is used to predict shoaling rates in inlets; Q_n is used for design of jetties and for predicting beach erosion on an open coast; Q_{rt} and $Q_{\ell t}$ are used for design of jetties and impoundment basins behind weir jetties. In addition, Q_g provides an upper limit on Q_n, $Q_{\ell t}$, and Q_{rt}.

Another representation of longshore transport rate (referenced in literature sources) is the immersed weight rate, I_ℓ, which is given in units of force per unit time (such as pounds per second or newtons per second). The conversion from Q to I_ℓ is

$$I_\ell = (\rho_s - \rho)\, g a' Q \qquad (3)$$

where

ρ_s = mass density of sand

ρ = mass density of water

g = acceleration of gravity

a' = volume solids/total volume (accounts for the sand porosity)

This equation is valid for any consistent set of units. Table 1 lists commonly assumed values for the parameters in equation (3). If better estimates of ρ_s, ρ, and a' are known for a specific site, they should be used in the equation. A discussion of equation (3) is provided by Galvin (1979).

Table 1. Values of parameters in equation (3).

Term	U.S. Customary[1]	Metric[2]
ρ_s	5.14 slugs/ft^3	2,650 kg/m^3
ρ (saltwater)	1.99 slugs/ft^3	1,025 kg/m^3
ρ (freshwater)	1.94 slugs/ft^3	1,000 kg/m^3
a'	0.6	0.6
g	32.2 ft/s^2	9.81 m/s^2

[1]Q in cubic feet per second; I_ℓ in pounds per second.

[2]Q in cubic meters per second; I_ℓ in newtons per second.

III. METHODS FOR COMPUTING LONGSHORE TRANSPORT RATE

The four methods described in the SPM for computing longshore transport are listed below in order of decreasing preference:

Method 1. The best way to predict longshore transport at a site is to adopt the best known rate from a nearby site, with necessary modifications for local conditions (assuming the rate from a nearby site is well established).

Method 2. If rates from nearby sites are unknown, the next best way to predict transport rates at a site is to compute them from data showing historical changes in the topography of the nearshore zone.

Method 3. If neither method 1 nor method 2 is practical, the accepted practice is to use measured or calculated wave conditions to compute a longshore component of "wave energy flux" which is related through an empirical curve to longshore transport rate.

Method 4. Another empirical method is available which estimates gross longshore transport rate from mean annual nearshore breaker height. The gross rate, so obtained, can be used as an upper limit on net longshore transport rate.

The following steps should be taken in selecting a method, depending on the data available. Figure 1 is a graphical representation of the decision process.

Step 1. Given a particular location where the longshore transport rate is needed, determine if there already exists an estimate of the rate for a nearby site (e.g., see SPM Table 4-6). If so, go to Section III, 1 of this report and use method 1; if not, proceed to step 2.

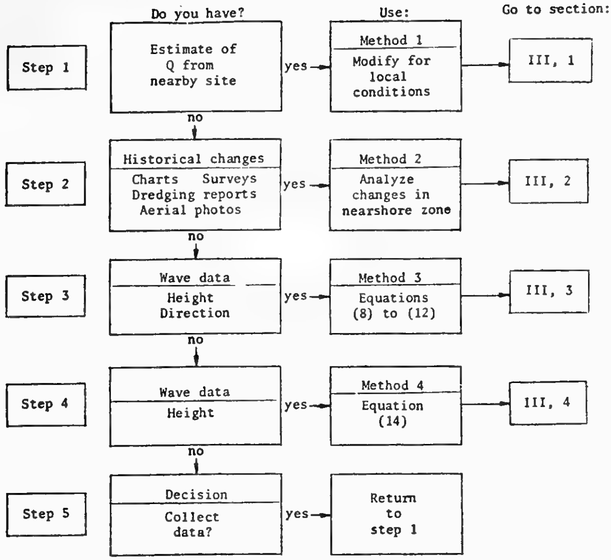

Figure 1. Selection guide to the four methods of estimating longshore transport rate.

Step 2. Study historical records of the area to see if sediment transport patterns and accretion or erosion volumes can be determined. Charts, surveys, dredging reports, beach nourishment reports, and aerial photos are primary sources. If these records exist, go to Section III, 2 and use method 2; if not, proceed to step 3.

Step 3. Study the wave data available for the area. If the data include at least wave height and direction, go to Section III, 3 and use method 3. If only wave height is available, go to step 4. If no wave data are available, go to step 5.

Step 4. With only an estimate of the wave height, go to Section III, 4 and use method 4. Remember that method 4 produces only an estimate of the gross longshore transport rate. If more than a gross estimate is needed, go to step 5.

Step 5. This situation is reached if no data are available for estimating longshore transport rate. The only choice here is to collect data if judged necessary after considering the importance to, and budget of, the project. If some data are collected, return to step 1.

1. Method 1.

The longshore transport rate at a given location can be estimated by using a value for the transport at a nearby site modified for local conditions. Engineering judgment is an important part of this method. The first step is to

decide how well the estimate for the nearby site predicted the longshore transport rate. For example, was the dredging maintenance schedule or the fillet growth of a jetty predicted with adequate accuracy? If satisfied that it was, the two sites should be compared for similarity. Some items to check are:

(1) Sediment sources and sinks (may affect one site but not the other; examples of sediment sources are eroding bluffs and river sediment discharge, and examples of sinks are offshore canyons and inlet shoals).

(2) Shoreline orientation (can control which waves reach the shoreline from which direction).

(3) Offshore bathymetry (controls refraction of waves, thereby affecting the wave climate; examples are shoals and canyons). The bathymetry also controls wave energy dissipation due to bottom friction (see Bretschneider and Reid, 1954).

(4) Offshore islands (can block waves from certain directions).

(5) Coastal structures (groins and jetties can block longshore transport; offshore and submerged breakwaters can block waves).

Based on this comparison of the two sites, an estimate can then be made of the longshore transport rate at the location in question by using engineering judgment to increase, decrease, or leave unchanged the transport rate at the nearby site.

2. Method 2.

Method 2 is an application of historical data which gives usable answers if the basic data are reliable and available at reasonable cost and the interpretation is based on a thorough knowledge of the locality.

Some indicators of the transport rate are the growth of a spit, shoaling patterns and deposition rates at an inlet, and the growth of a fillet adjacent to a jetty or groin. As an example, the longshore transport rate across Cold Spring Inlet, New Jersey, was estimated based on fillet growth next to the updrift jetty and surveys of the surrounding area to account for the sand that was not impounded by the jetty (Beach Erosion Board, 1953). The rates of growth for Sandy Hook, New Jersey (U.S. Army Engineer District, New York, 1954) and for Sheshalik Spit, Alaska (Moore and Cole, 1960), were used to estimate longshore transport rate. Bruno and Gable (1976) measured the deposition behind the offshore breakwater and adjacent to the updrift jetty at Channel Island Harbor, California, to find the longshore transport rate. Various methods of finding longshore transport rates including surveys, aerial photos, dredge records of a tidal inlet, and a quantitative analysis of eroding sources of sand are discussed in Beach Erosion Board (1954).

3. Method 3.

This method of computing longshore transport rate is based on the empirical relationship between the longshore component of wave energy flux entering the

surf zone and the immersed weight of sand moved. Both have units of force per unit time

$$I_\ell = KP_\ell \tag{4}$$

where I_ℓ is the immersed weight transport rate (force/time), K a dimensionless coefficient, and P_ℓ the longshore component of wave energy flux (force/time). P_ℓ is defined as

$$P_\ell = \frac{\rho g}{16} H^2 C_g \sin 2\alpha \tag{5}$$

where H is the wave height, C_g the wave group velocity, and α the angle the wave crest makes with the shoreline. If the breaker values of the wave characteristics (H_b, C_{gb}, α_b) and the significant wave height (H_s) are put into equation (5), the energy flux factor results

$$P_{\ell s} = \frac{\rho g}{16} H_{sb}^2 C_{gb} \sin 2\alpha_b \tag{6}$$

The significant wave height is the average height of the one-third highest waves in a given wave condition. (See Section 3.21 of the SPM.)

The empirical relationship between longshore transport rate and $P_{\ell s}$ is based on field measurements. Since the immersed weight of sand moved in the field cannot be measured directly, the volume of sand moved is usually determined. Therefore, Q is substituted for I_ℓ in equation (4), by using equation (3) to produce

$$Q = \frac{K}{(\rho_s - \rho)\ ga'} P_{\ell s} \tag{7}$$

The SPM plots field data points of Q versus $P_{\ell s}$ as shown in Figure 2 to produce the empirical relation

$$Q\left[\frac{yd^3}{yr}\right] = 7500 \left[\frac{yd^3/s}{lb/yr}\right] P_{\ell s} \left[\frac{ft\text{-}lb}{ft/s}\right] \tag{8}$$

where the dimensions of the factors are given in brackets. Note that the constant (7500) is dimensional. Using this dimensional constant and the values in Table 1, K in equation (7) is found to be 0.39. The scatter of the data points in Figure 2 shows that the value of Q estimated from equation (8) is accurate to only ±50 percent. This can be seen by drawing a line 50 percent higher and a line 50 percent lower than the design curve in Figure 2. These two lines form an envelope of the data points.

Table 2 presents equations (9) to (12), which are alternate forms of $P_{\ell s}$. The choice of one of these equations depends on the data available. For example, if breaker wave height and direction are known, equation (9) should be used; if deepwater wave height and direction are known, equation (10) should be used. As a general rule, the closer the data have been collected to the surf zone, the better the data are for estimating $P_{\ell s}$. Therefore, if both deepwater and breaker values of wave height and direction are available, with comparable accuracy, the latter should be used. Figures 3 and 4 plot values of Q for different input data combinations based on equations (9) and (10).

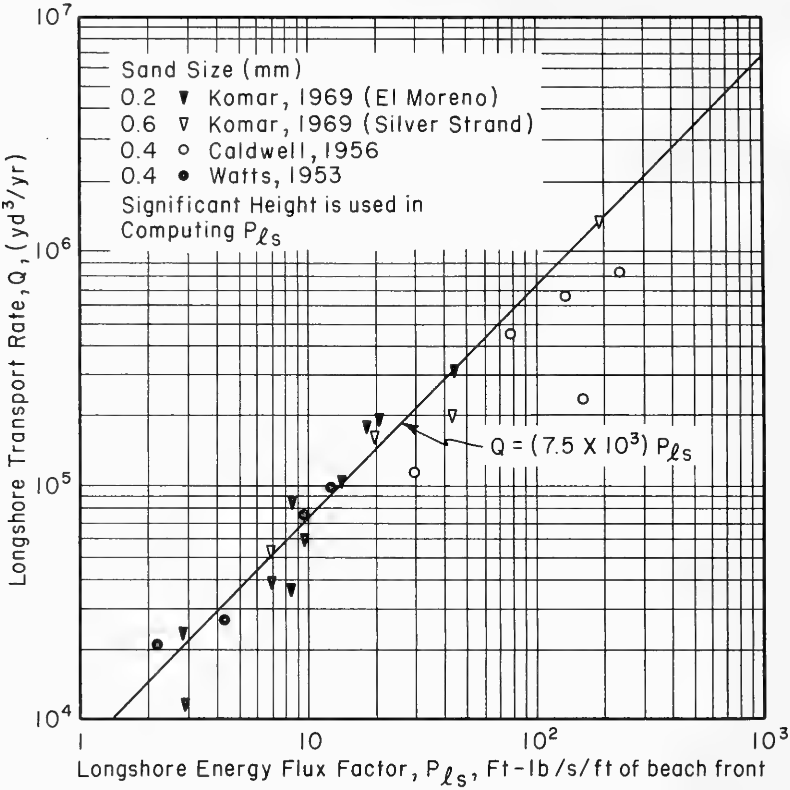

Figure 2. Design curve for longshore transport rate versus energy flux factor; only field data are included (from U.S. Army, Corps of Engineers, Coastal Engineering Research Center, 1977).

Table 2. Approximate formulas for computing longshore energy flux factor, $P_{\ell s}$, entering the surf zone.

Equation	$P_{\ell s}$ (ft-lb/s/ft of beach front)	Data required (ft-s units)
(9)	$32.1\ H_{sb}^{5/2}\ \sin 2\alpha_b$	H_{sb}, α_b
(10)	$18.3\ H_{so}^{5/2}\ (\cos \alpha_o)^{1/4}\ \sin 2\alpha_o$	H_{so}, α_o
(11)	$20.5\ TH_{so}^2\ \sin \alpha_b\ \cos \alpha_o$	T, H_{so}, α_o, α_b
(12)	$100.6\ (H_{sb}^3/T)\ \sin \alpha_o$	T, H_{sb}, α_o

NOTE.--Subscript *b* = breaker value; *o* = deepwater value; and *s* = significant wave height.

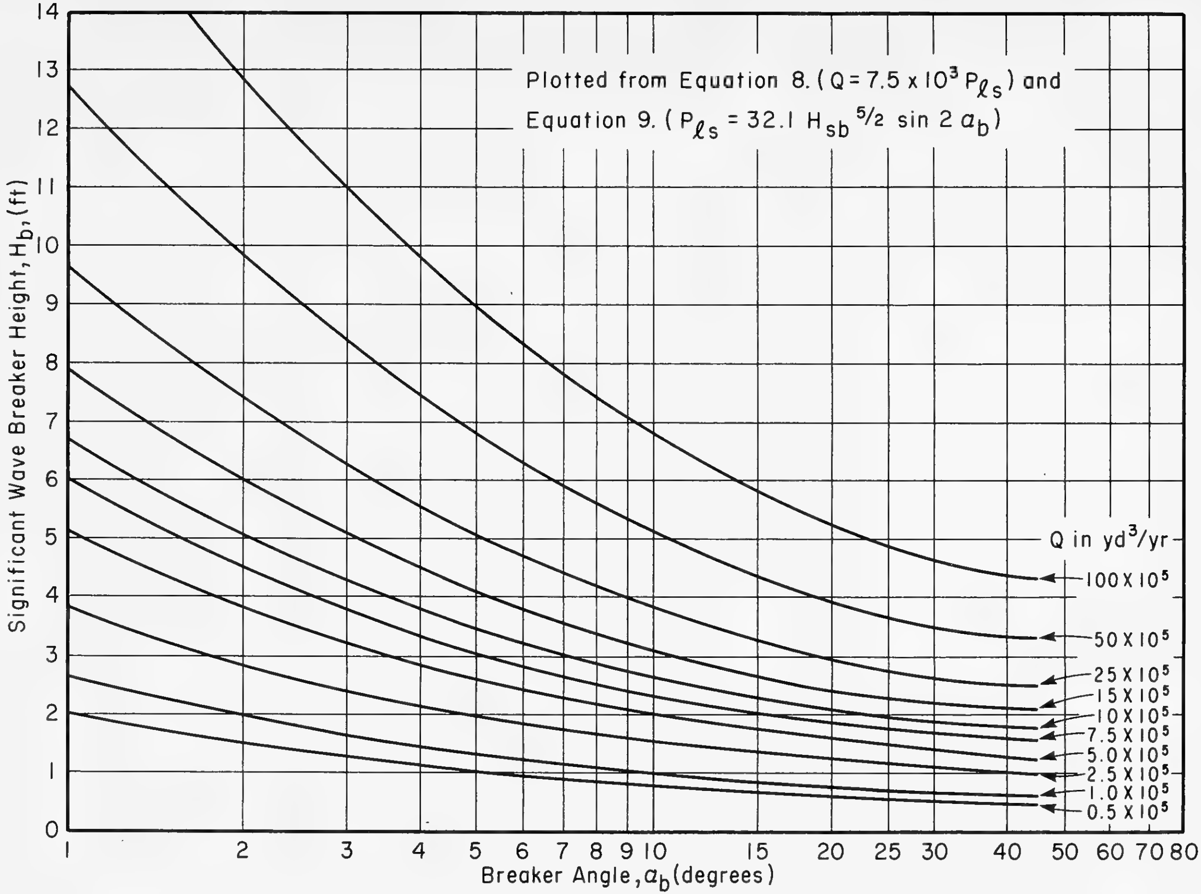

Figure 3. Longshore transport rate as a function of breaker height and breaker angle (from U.S. Army, Corps of Engineers, Coastal Engineering Research Center, 1977).

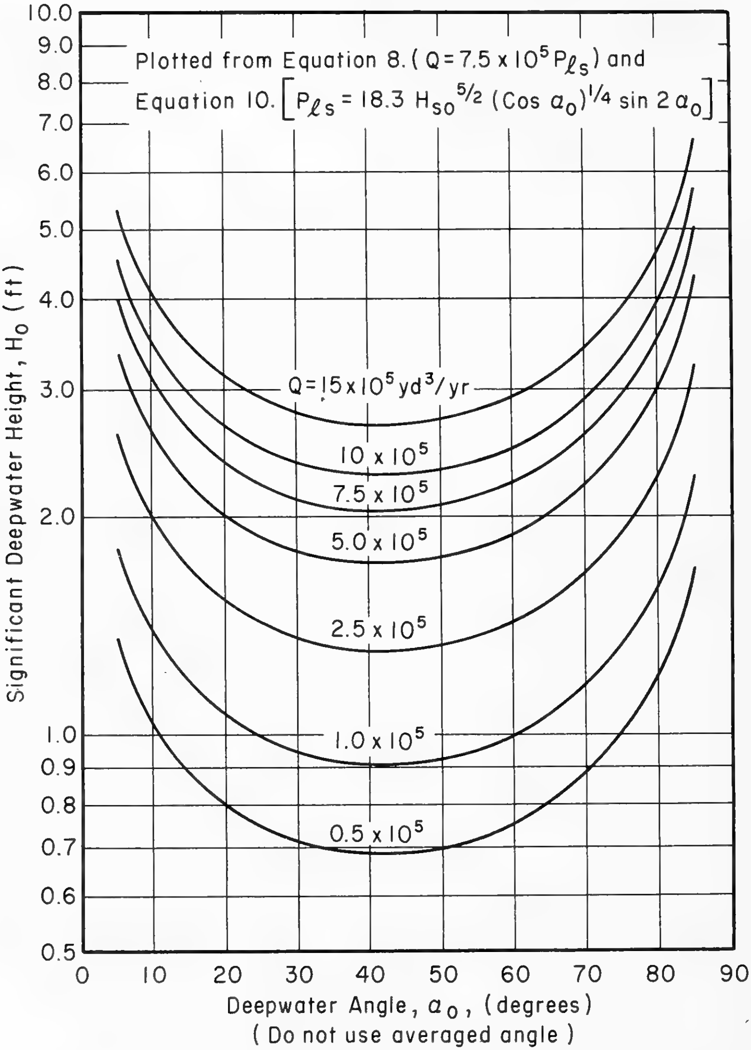

Figure 4. Longshore transport rate as a function of deepwater height and deepwater angle (from U.S. Army, Corps of Engineers, Coastal Engineering Research Center, 1977).

To calculate an average $P_{\ell s}$, a value of $P_{\ell s}$ should be calculated for each combination of wave height and angle available. These values can then be used to find the average $P_{\ell s}$. It is incorrect to compute an average wave height and an average wave angle and then use them to find an average $P_{\ell s}$.

Computing $P_{\ell s}$ using LEO current data is described in Walton (1980).

4. Method 4.

The SPM empirically relates the gross longshore transport rate in cubic yards per year to the mean annual breaker height, $\overline{H}_b$ in feet, by the equation

$$Q_g \left[\frac{yd^3}{yr}\right] = 2 \times 10^5 \left[\frac{yd^3}{ft^2/yr}\right] \overline{H}_b^2 \left[ft^2\right] \tag{9}$$

The gross rate, as defined earlier in equation (1), is the total amount of sand moving in both directions. If the net transport, Q_n, is needed, this method is unsuitable.

IV. SUMMARY OF GUIDANCE

An engineer confronted with the problem of estimating the longshore transport rate at a project site must first survey all available data. Following the selection guide in Figure 1, the appropriate SPM method should be used if the engineer has (a) a rate from a nearby site (method 1); (b) historical changes in topography (method 2); (c) wave height and direction (method 3); and (d) wave height data (method 4).

If enough data, time, and money are available to use more than one method, the engineer can, and is encouraged to, estimate the transport rate using all methods possible. The most preferred method (see Section III) should be used for the design; the other methods should be used as checks. For example, if method 3 is used to find the net transport rate, Q_n, then method 4 can also be used to find the gross transport rate, Q_g. This will allow the engineer a check to make sure Q_n does not exceed Q_g.

A combination of methods can also be used if not enough data are available for any one method to be used completely. Jarrett (1977) presents an example of using methods 2 and 3 to estimate Q_n and then checking the results with Q_g found using method 4.

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Vitale, Philip

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